Hydrogen in the Heavy Duty Market?

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What are the issues we trying to solve?

- **Transportation's dependence on petroleum**
  - **Increasing dependence on foreign oil, particularly from unstable regions**
- **Vulnerable domestic & international energy infrastructures**
  - **Oil and natural gas pipelines**
  - **Few and vulnerable ports of entry**
- **Urban air pollution**
  - **Criterion gas emission (NO_x, HC, PM, CO …)**
- **Threat of climate change**
  - **Atmospheric concentration of [CO_2], [CH_4] …**

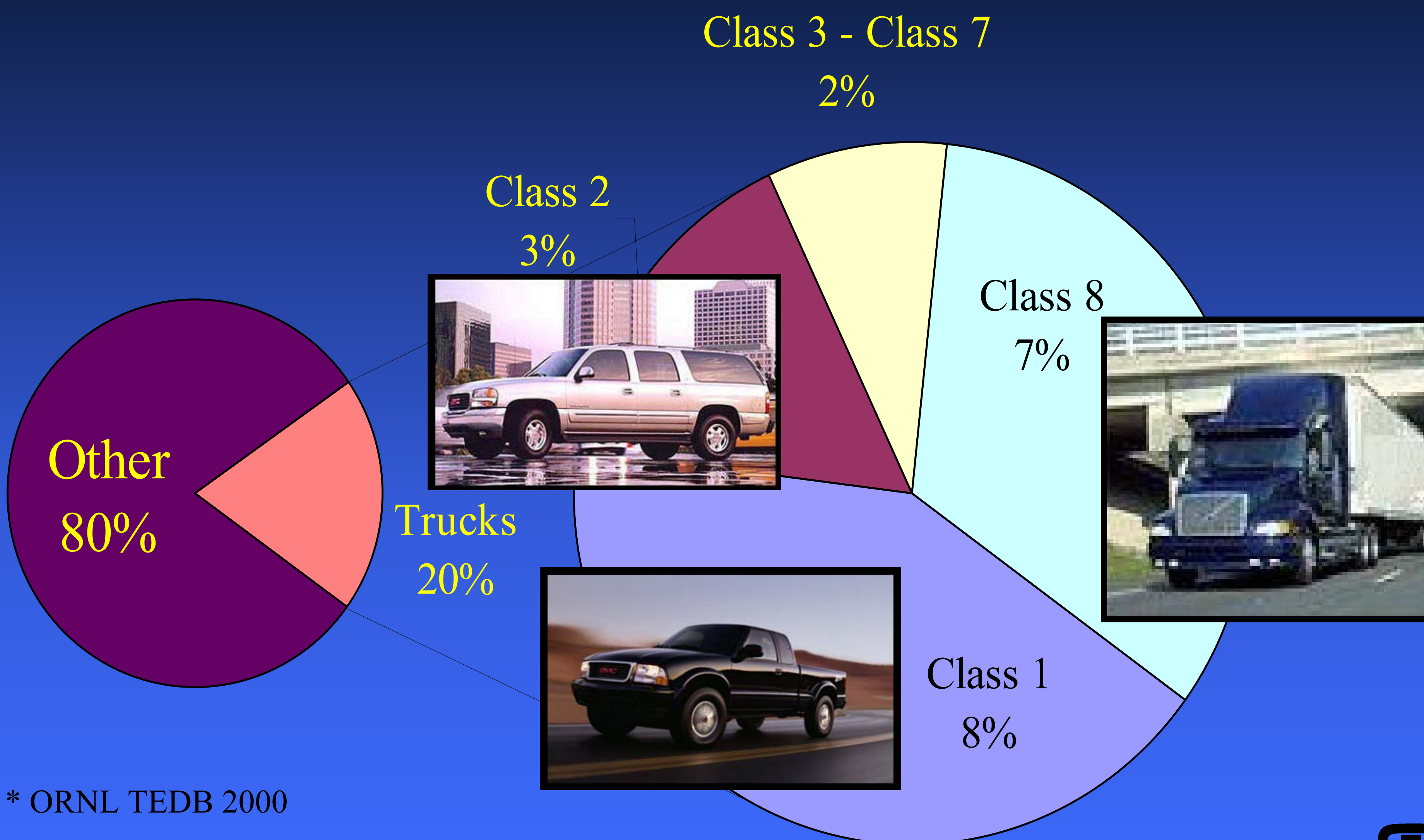
Stabilizing Atmospheric CO_2 Concentrations …

- **The residence time for CO_2 in the atmosphere is on the order of 120 years ***
  - **The concentration of CO_2 in the atmosphere is a result of cumulative net emissions ****
    - From pre-industrial times to the indefinite future, by every economically developing country, everywhere on the planet . . . <u>and with most emissions yet to come **</u>
- **Net Emissions must eventually decline to virtually ZERO . . . <u>whatever the concentration target might be</u>. ****

***** Stabilizing Atmospheric Carbon: The NCCTI Challenge,***
Jae Edmonds, John Clarke
NCCTI Integration Group
Measurement, Monitoring and Validation Workshop, September 26, 2001

* Combustion's Impact on the Global Atmosphere, M. J. Prather, J.A. Logan
25th symposium (International) on Combustion/The Combustion Institute
1994/pp 1513-1527

Estimated distribution of CO_2 emissions



* ORNL TEDB 2000

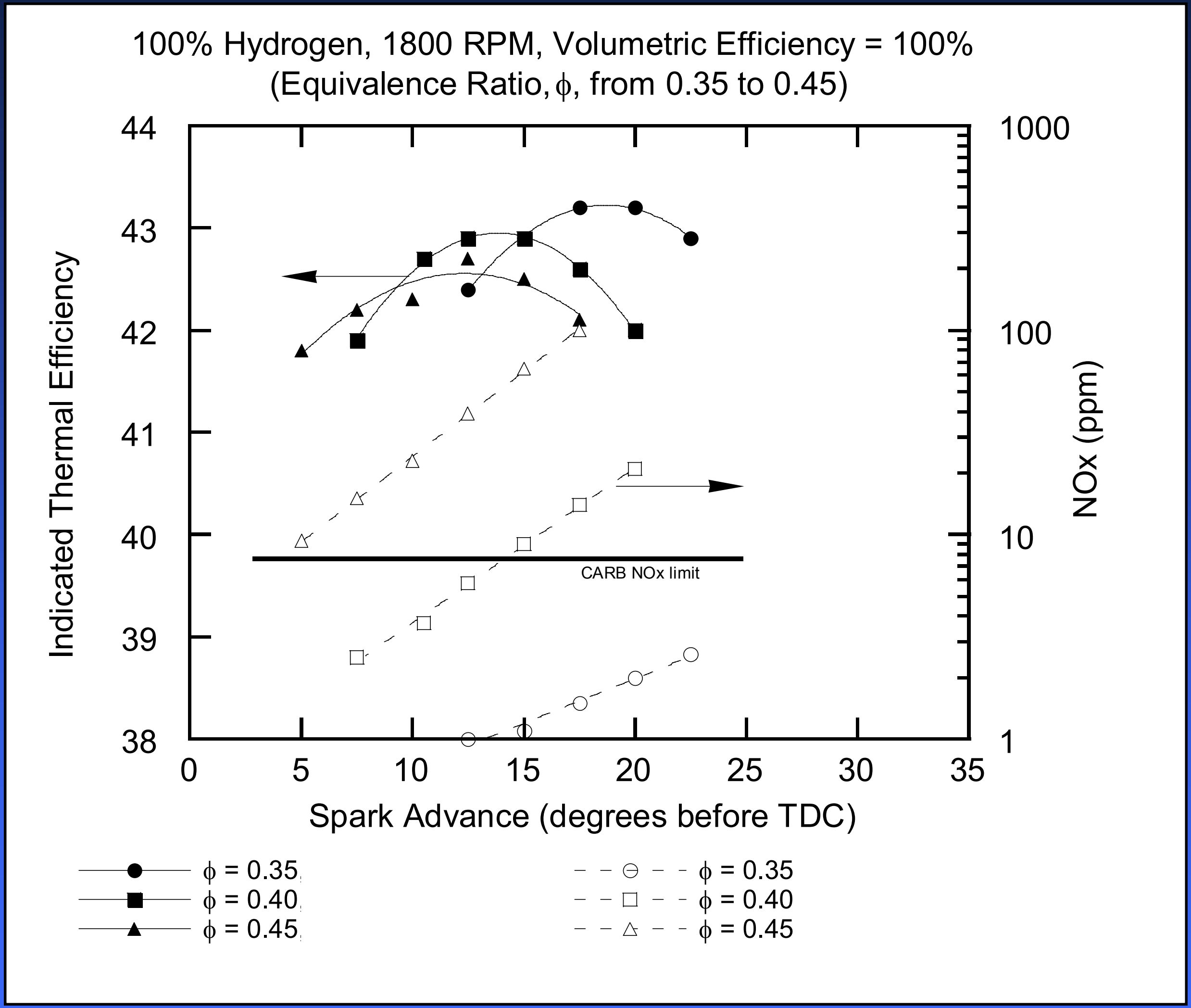
Solutions for the Heavy Duty Market

- **Dependence on Petroleum**
  - **Hydrogen, natural gas and/or bio-fuels**
- **Energy supply vulnerability**
  - **Use hydrogen as an energy carrier made from the broadest spectrum of domestic energy feed stocks**
    - **fossil fuels, coal (with CO_2 sequestration), renewables …**
- **Urban air quality (criterion gas emission)**
  - **Conventional diesel fuels with aggressive after treatment (after treatment technologies are under development)**
  - **Natural gas fueled vehicles with after treatment**
  - **Hydrogen fueled vehicles with or without after treatment**
- **Climate change**
  - **Hydrogen and/or bio-diesel fueled vehicles**

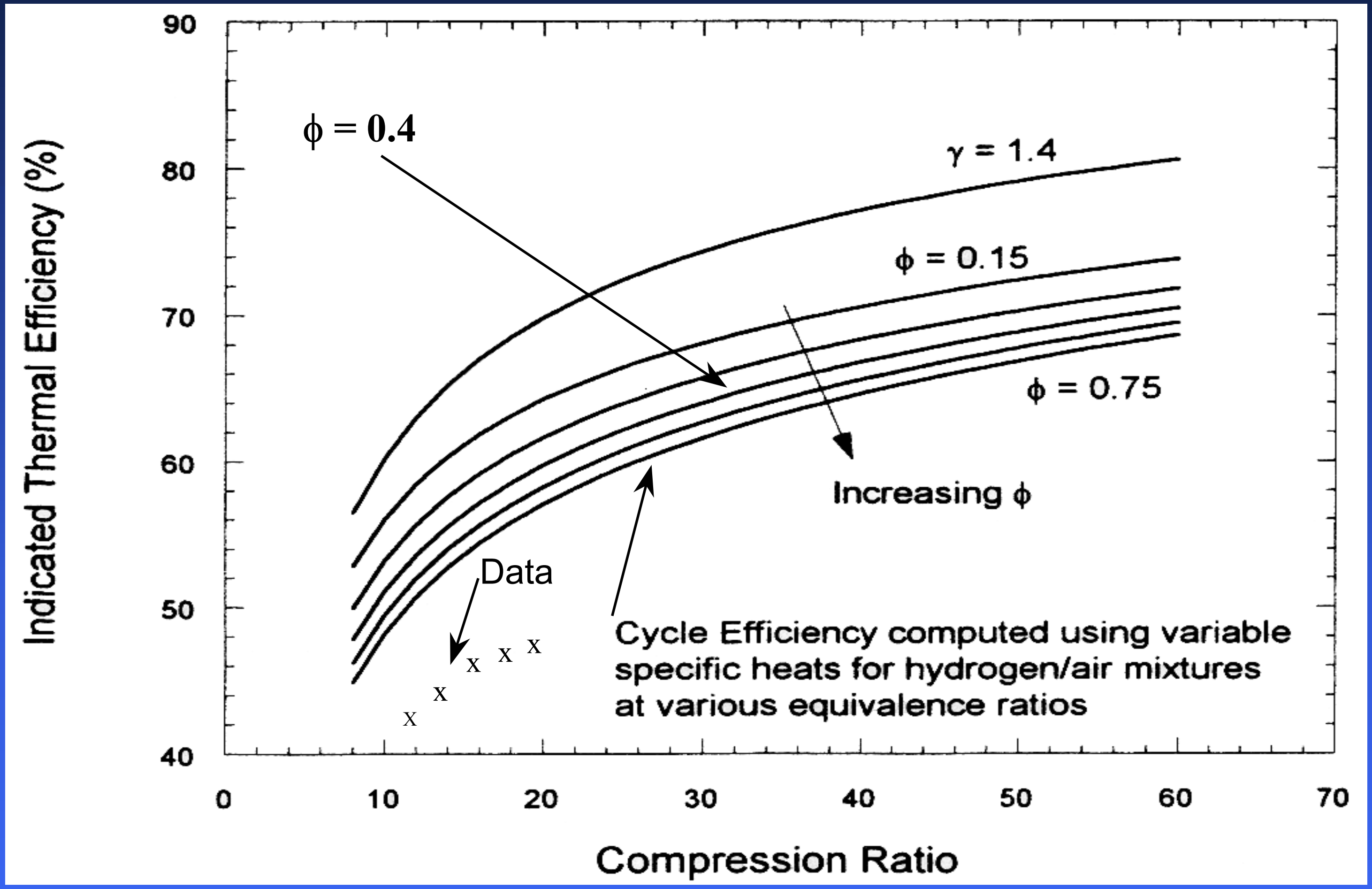
Requirements on hydrogen conversion technologies for vehicular use

- **Highly efficient energy conversion**
- **Power density must be sufficiently high to be packaged in a vehicle**
- **Environmentally benign**
- **Cost effective hardware**
- **Compatible with existing infrastructure**
  - **manufacturing, service, supplies, maintenance**
  - **refueling**
- **Energy storage density sufficiently high to provide acceptable range**

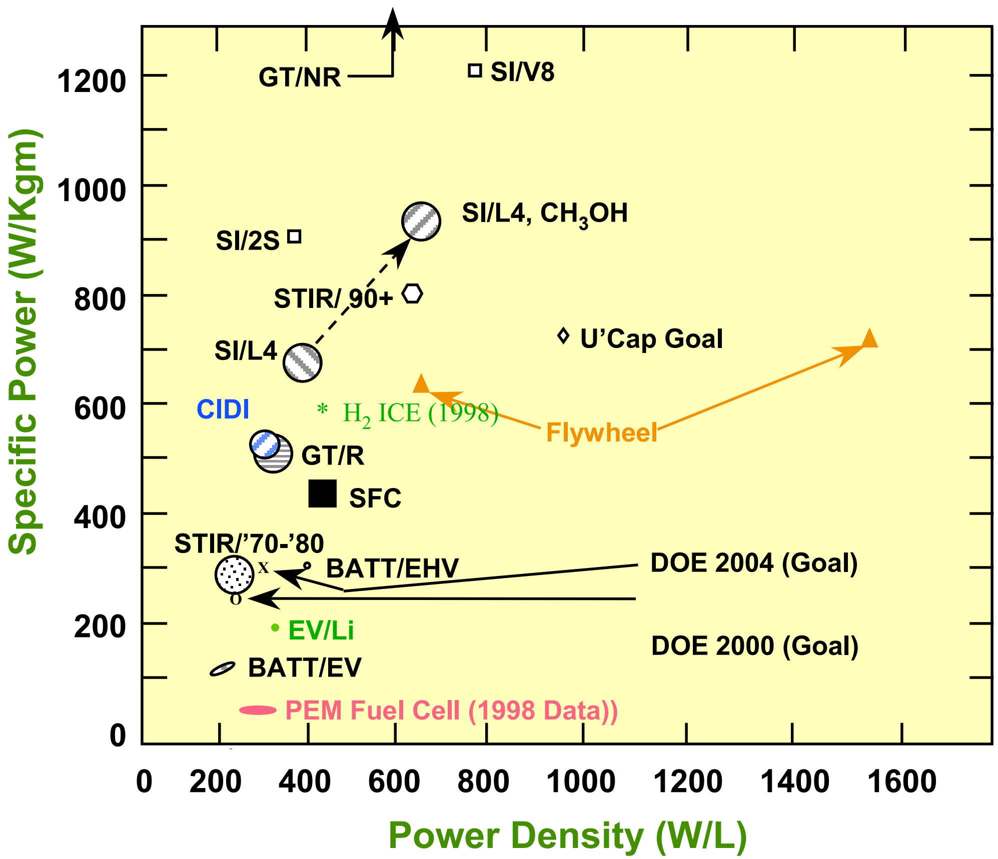
What is possible with an optimized H_2 fueled internal combustion engine (ICE)?



What is possible with an optimized H_2 fueled ICE?



Energy conversion system power densities



Mass and space requirements for energy-conversion and energy-storage devices. (Based on engine rated / max-power condition)

<u>KEY:</u>

SI / L4 = 4-stroke spark ignition, Fe-block L4
SI / 2S = 2-stroke spark ignition, AL-block L3
SI / V8 = 4-stroke spark ignition, AL-block V8
CIDI = direct injection turbocharged diesel
GT / R = regenerative gas turbine, circa 1950-70
GT / NR = nonregenerative gas turbine, circa 1950
STIR /'70-'80 = Stirling, circa 1970-80
STIR /'90+ = Stirling (swash-plate), circa 1990
BATT / EV = current batteries for electric car
EV / Li = anticipated lithium electric car battery
BATT / EHV = Pb-acid battery for hybrid vehicle
FLYWHEEL = electro-mechanical battery
U'CAP GOAL = goal for ultracapacitor
SFC = Solid Oxide Fuel Cell (500°C)
H_2 ICE= Lean burn optimized ICE - AL block

DOE Goals are for the PEMFC system excluding the fuel processor

Original source:
SAE International

What is possible for an optimized ICE?

- **Maximum measured indicated efficiency ~ 47%**
  - **Estimated break thermal efficiency ~ 40%**
- **HC, CO all near zero**
  - **Trace amounts from lubricating oil**
- **Current H_2 ICE prototypes are based on production hardware**
  - **ICE's are cost effective today.**
- **Engine out Dial-a-NOx value ~ 5-6 ppm**
- **With after treatment NOx values can be near zero**
  - **Proof of concept measured NOx below detectability of 0.5 ppm***

***James Heffel, University of California, Riverside, College of Engineering – Center for Environmental Research and Technology (CE-CERT); Personal Communication Under contract to Sandia National Laboratories, funding from the Hydrogen Program Office; OPT: To appear in the International Journal of Hydrogen Energy**

Words from the DOE post 9/11

- **Secretary Abraham's Pronouncement on Missions of the DOE**
  - **"… I would add to this list two priorities that deserve special mention.**

    The first involves the unique technological contribution we can make to our energy and national security by finding *new sources of energy*. Whether it is fusion or a *hydrogen economy*, or ideas that we have not yet explored …"

- **FreedomCAR announcement on January 9, 2002**
  - **Replaces PNGV**
  - **Focuses on fuel cells and hydrogen infrastructure**

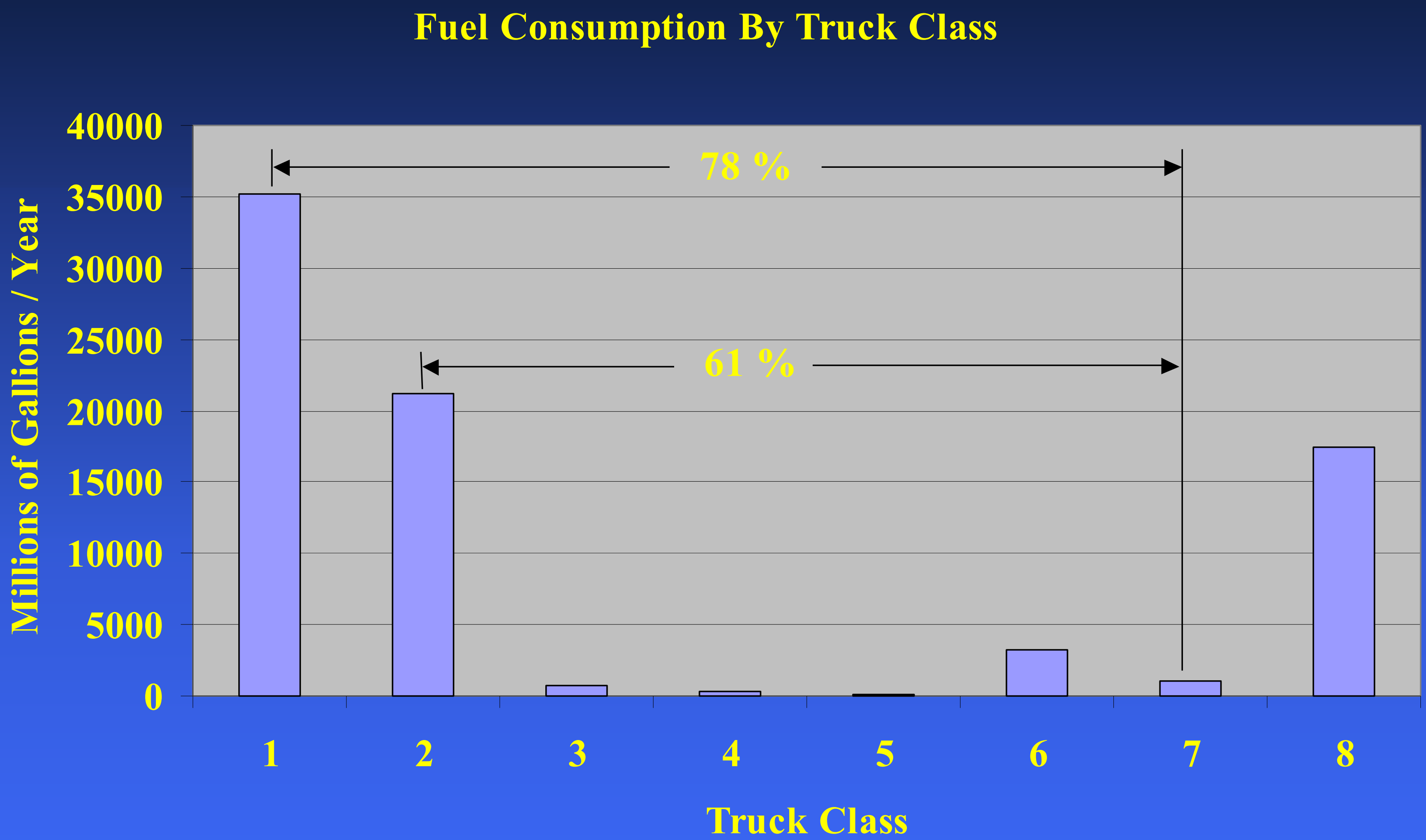
Range ?

Diesel			Hydrogen							
			@ 5000 psi		@ 10000 psi		Liquid		Hydride	
class	Ave mi/day	Estimated Storage Capacity (l)	Range (Miles)	% daily average range	Range (Miles)	% daily average range	Range (Miles)	% daily average range	Range (Miles)	% daily average range
Class 1	53	152	45	85%	76	143%	141	264%	99	186%
Class 2	52	152	37	72%	63	121%	115	223%	81	157%
Class 3	63	152	29	46%	48	77%	89	141%	62	100%
Class 4	66	265	47	71%	79	120%	145	221%	102	155%
Class 5	24	265	40	167%	68	281%	124	516%	88	364%
Class 6	55	265	38	70%	64	117%	117	215%	83	152%
Class 7	142	379	47	33%	79	55%	144	101%	102	72%
Class 8	192	758	88	46%	149	77%	273	142%	193	100%

Average range for class 8 on diesel ~1000 mi

* Values estimated from data provided by ORNL TEDB 2000

Fuel Usage



Class 1 thru 7 represents 78 %; 2 thru 7 represents 61% of the total fuel consumed

* Values estimated from data provided by ORNL TEDB 2000

Conclusions – There is no Holy Grail

- **Hydrogen**
  - **Solves all the problems**
    - **Energy diversity, urban air quality, climate change, …**
    - **Hydrogen refueling infrastructure is coming - FreedomCAR**
  - **BUT - it has a low energy density hence, range is reduced.**
    - **Hydrogen may work in those fleet applications where range is limited to < 100 miles/day and centralized refueling is feasible.**
- **Bio-Diesel**
  - **Does not quite solve all the problems**
    - **Solves zero-net CO_2, good energy density (90% of conventional diesel fuel), domestically produced …**
  - **BUT - Criterion gas emission remains a problem**
    - **When engine and after treatment technologies are developed for conventional diesel fuels they should work for bio-diesel fuel as well. Indeed, bio-diesels may be easier to clean up in many respects.**

Presentation End